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RESEARCH MEMORANDUM

THE HYDRODYNAMIC PLANING LIFT OF FOUR SURFACES AS MEASURED IN A 200-FPS FREE JET

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THE HYDRODYNAMIC PLANING LIFT OF FOUR SURFACES AS MEASURED IN A 200-FPS FREE JET

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SUMMARY

Hydrodynamic planing lifts were obtained in a free jet at speeds from 80 to 200 fps for four planing surfaces. The jet was rectangular in shape and was 3 inches wide by 3/4 inch deep. The four models tested were a flat plate, a longitudinally curved model, a cylinder, and a hydro-ski with a complex-shaped bottom. The lift data were analyzed to show the effect of speed, planing-surface configuration, trim, and wetted-length-beam ratio at these high speeds. The data for the flat-plate and the hydro-ski were compared with similar data obtained in towing tanks.

No large effect of speed was obtained on any of the models tested, but the lift coefficients for the flat plate and the longitudinally curved surface appeared to increase slightly with speed in the higher portion of the speed range. The lift coefficients obtained for the flat plate and the hydro-ski on the free jet were less than those obtained for similar surfaces in comparatively unrestricted towing tanks. For the trims and length-beam ratios investigated, the ratio of tank lift data to jet lift data for the flat plate appeared to be a function of the ratio of the height of the trailing edge of the model above the lower jet boundary to the wetted length.

INTRODUCTION

The take-off speeds of water-based airplanes have been increasing rapidly and are now approaching 200 fps. This speed is much greater than the maximum speed, 90 fps, at which hydrodynamic data are currently obtainable in the towing tanks. Furthermore, compromise with aerodynamic considerations often dictates hydrodynamic surfaces of complex curvature for high-speed, water-based airplanes. These curved surfaces,

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at high full-scale speeds, are likely to induce negative pressures of sufficient magnitude to result in radical flow changes such as cavitation which is a function of absolute speed and not model size. At the comparatively low towing-tank speeds, the negative pressures induced by these surfaces may not be of sufficient magnitude to cause appreciable changes in flow characteristics. Therefore, it has become increasingly important to determine to what extent, if any, hydrodynamic force characteristics at full-scale speeds differ from those obtained at the lower testing speeds.

In this investigation, hydrodynamic lifts were obtained at speeds from 80 to 200 fps for four different planing surfaces: a flat plate, a longitudinally curved surface, a cylinder, and a complex curved surface. Comparisons were made to obtain some effects of speed, planing-surface configuration, trim, and wetted-length-beam ratio. The tests were made on 1-inch-beam models, planing on the surface of a 3-inch-wide by 3/4-inch-deep rectangular free-water jet. In order to obtain some indication of the boundary corrections involved, some of the data were compared with similar data obtained in the towing tanks.

SYMBOLS

B nominal width of jet stream, 0.25 ft

b beam of models, ft

C empirical correction factor, C_{L_2}/C_{L_1}

C_L hydrodynamic lift coefficient, $\dfrac{L}{\frac{\rho}{2}V^2S}$

C_{L_1} hydrodynamic lift coefficient obtained from jet data

C_{L_2} hydrodynamic lift coefficient obtained from tank data

d draft at trailing edge of model (measured vertically from upper edge of nozzle exit), ft

H nominal height of jet stream, 0.0625 ft

h height of trailing edge of model above the lower edge of the jet, $H - d$, ft

L lift, lb

l wetted length of models, $d/\sin \tau$, ft

P static pressure in tank at level of nozzle entrance, lb/sq in. gage

S wetted area of models, $bd/\sin \tau$, sq ft

V speed equivalent to static pressure in tank at level of nozzle, $\sqrt{\frac{144P}{\rho/2}}$, fps

τ trim (angle between reference line and the jet center line), deg

ρ mass density of water, 1.94 slugs/cu ft

DESCRIPTION OF MODELS

The four brass models investigated, a flat plate, a longitudinally curved surface, a cylinder, and a hydro-ski with a complex-shaped bottom are shown in figure 1. The flat plate was 6 inches long and had a beam of 1 inch. The longitudinally curved surface was 6 inches long with a beam of 1 inch and a radius of curvature of 13.55 inches. The cylinder was a right cylinder 6 inches long with a diameter of 1 inch. The hydro-ski was a 1/25-scale model of the aft portion of a full-size hydro-ski now in use on a high-speed water-based airplane. The hydro-ski had a curved chine on the port side and a sharp chine on the starboard side. This model was also 6 inches long with a mean average beam of approximately 1 inch.

APPARATUS AND PROCEDURE

A schematic drawing of the test equipment is shown in figure 2. The models were tested on the surface of the 3-inch-wide by 3/4-inch-deep free-water jet described in reference 1. A model mounted for testing is shown in figure 3. The models were rigidly attached to an electrical strain-gage balance housed in the mounting shown. The photographs in figure 4 show the models under test.

The models were tested at fixed trims of 4°, 8°, and 12° and at fixed drafts corresponding to wetted lengths of 1, 2, 3, and 4 inches, except where, due to the limited depth of the jet, a wetted length of 3.6 inches was the maximum attainable at 12° trim. By limiting the air supply as described in reference 1, each test was made at decaying speeds varying from about 200 fps to 80 fps.

Trim angles were taken as the angle between a reference line on the model and the jet center line. For the flat plate and the cylinder, the reference line was the lower profile line. For the longitudinally curved model, the reference line was the chord subtended by the wetted-arc length. The relation of the hydro-ski reference line to the hydro-ski configuration is shown in figure 5. The draft was measured as the depth of the trailing edge of the model below the horizontal plane through the top of the nozzle exit. Wetted lengths were determined by dividing the draft by the sine of the trim angle. The measured lifts were converted to coefficients based on a nominal wetted area (square feet) obtained by multiplying the wetted length l by the beam b. The beam for all the models, except the hydro-ski, was constant and equal to 0.083 foot. For the hydro-ski the beam varied and the mean beam of the model over the wetted length was used. The mean beams for the various wetted lengths are shown in the table of figure 5. Lift and the static pressure at the nozzle entrance were recorded simultaneously on an oscillograph. The jet speeds were calculated by assuming complete conversion of this pressure to dynamic pressure in the jet.

The accuracy to which lift coefficient could be determined from the oscillograph record is shown in figure 6. The lift trace could be read to an accuracy of ±0.01 inch on the oscillograph record, which corresponds to ±0.60 pound of lift. As shown in figure 6 the error in lift coefficient would be greater at the lower speeds because, even though the error in pounds is the same at all speeds, the lift coefficient is a function of the reciprocal of the square of the speed.

RESULTS AND DISCUSSION

The photographs in figure 4, for speeds of 80 and 200 fps, indicate no major difference in the flow patterns for any of the models except the cylinder. The layer of water clinging to the surface of the cylinder at 200 fps did not flow around the upper surface of the cylinder to the extent that it did at 80 fps.

The data for all the models are presented in figure 7 for trims of 4°, 8°, and 12°, as plots of lift coefficient against speed with length-beam ratio as the parameter. No large effect of speed was obtained on any of the models tested, but the lift coefficients for the flat plate and the longitudinally curved surface appeared to increase slightly with speed in the higher portion of the speed range. This apparent increase in lift coefficient may possibly be attributed wholly or in part to the effect of the restricted boundaries of the jet, the method of obtaining wetted area, and a Reynolds number effect.

The variation of lift coefficient with length-beam ratio for all models followed the conventional pattern for planing surfaces. There was a large decrease in lift coefficient from a length-beam ratio of 1 to a length-beam ratio of 2, and then a more gradual decrease as the length-beam ratio was further increased to a value of 4.

The effect of trim for length-beam ratios of 1, 2, 3, and 4 is shown in figure 8 for all the models. The data at 12° for all the models were extrapolated from a length-beam ratio of 3.6 to a length-beam ratio of 4 for construction of this figure. Lift coefficients are plotted against trim for a speed of 80 fps. Curves of lift data obtained from tests in the Langley tank no. 1 (ref. 2) on a flat plate, which had a beam of 4 inches, are included for comparison. For a length-beam ratio of 1, figure 8(a), the lift coefficients of the flat plate were greater than those of any of the other models tested on the jet except that the lift coefficient for the curved plate appeared to become approximately the same as that for the flat plate at a trim of 12°.

The disparity between the flat plate, the longitudinally curved surface, and the hydro-ski became smaller with increase in length-beam ratio to a value of 2 and vanished completely with further increase to 3 and 4. The lift coefficient of the cylinder was much lower than that of the other models at all length-beam ratios investigated.

At all length-beam ratios the lift coefficients for the flat plate determined from tank data were greater than those obtained from jet data. The ratios of the flat-plate lift coefficients C_{L_2} obtained in the tank to those obtained in the jet C_{L_1} for a speed of 80 fps are given in the tables of figure 8.

These ratios are plotted in figure 9 as values of an empirical correction factor C against the ratio of the height of the trailing edge of the model above the lower edge of the jet h to the wetted length l. The ratios vary from approximately 2.3 for an h/l of zero to approximately 1.2 for values of h/l of 0.6 and greater. The curve faired through these points indicates that, for the trims and length-beam ratios investigated, the empirical correction factor is to a large extent a function of h/l. Pending determination of the possible effect of parameters other than h/l, this curve may be considered to be a reasonable basis for making corrections to the lift forces measured in the jet. To determine the extent to which this is true will require further investigation and data for a more comprehensive range of pertinent parameters. For example, the data in this report were for only one model beam, one width of jet, and one depth of jet.

In figure 10(a) flat-plate lift coefficients obtained from jet data, computed by applying the proper correction factor from figure 9 to the flat-plate jet data in figure 8, are compared with the flat-plate tank data curves taken from figure 8. The fairly close agreement between the corrected flat-plate jet data and the flat-plate tank data indicates that the faired curve in figure 9 is suitable for correcting flat-plate data obtained in the jet over the ranges investigated.

In order to determine the applicability of the flat-plate correction factor to one of the other models, the hydro-ski jet data were corrected and compared in figure 10(b) with hydro-ski data obtained in a towing tank. The hydro-ski lift coefficients obtained from jet data, corrected by applying the proper correction factor from figure 9 are compared with hydro-ski data for a $2\frac{1}{2}$-inch beam model obtained in the Langley tank no. 2 in an investigation as yet unreported. Good agreement was obtained between the jet hydro-ski data, corrected by applying the proper correction factor from figure 9, and the hydro-ski data obtained in the comparatively unrestricted tank.

CONCLUDING REMARKS

The results of the investigation indicate that no large effect of speed was obtained on any of the models tested, but the lift coefficients for the flat plate and the longitudinally curved surface appeared to increase slightly with speed in the higher portion of the speed range. This apparent increase in lift coefficient may possibly be attributed, wholly or in part, to the effect of the restricted boundaries of the jet, the method of obtaining wetted area, and a Reynolds number effect.

The lift coefficients obtained for the flat plate and the hydro-ski on the free jet were less than those obtained for similar surfaces in comparatively unrestricted towing tanks. For the trims and length-beam ratios investigated, the ratio of tank lift data to jet lift data for the flat plate appeared to be a function of the ratio of the height of the trailing edge of the model above the lower jet boundary to the wetted length. This would indicate that the difference between the jet data and the towing-tank data would be due principally to the effect of the jet boundaries.

The empirical correction factor appears to be a reasonable basis for correcting the jet data presented in this report.

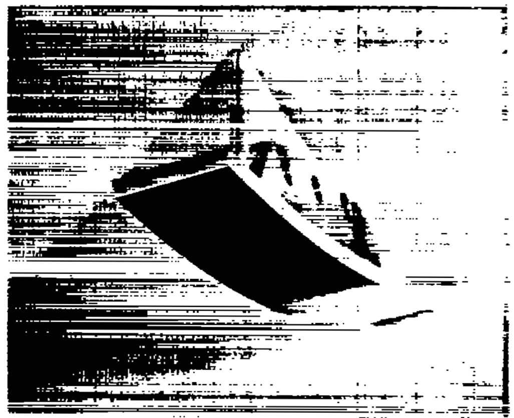
Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 13, 1954.

REFERENCES

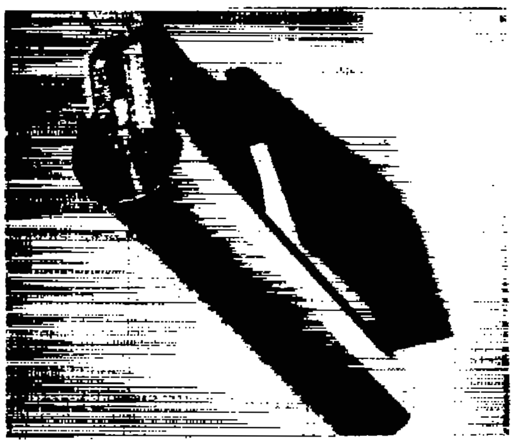
1. Weinflash, Bernard, and McGehee, John R.: An Investigation of a Method for Obtaining Hydrodynamic Data at Very High Speeds With a Free Water Jet. NACA RM L54D23, 1954.

2. Weinstein, Irving, and Kapryan, Walter J.: The High-Speed Planing Characteristics of a Rectangular Flat Plate Over a Wide Range of Trim and Wetted Length. NACA TN 2981, 1953.

Flat plate



Longitudinally curved surface



Cylinder

Hydro-ski

L-83688

Figure 1.- Planing surfaces investigated. (Quarter front view.)

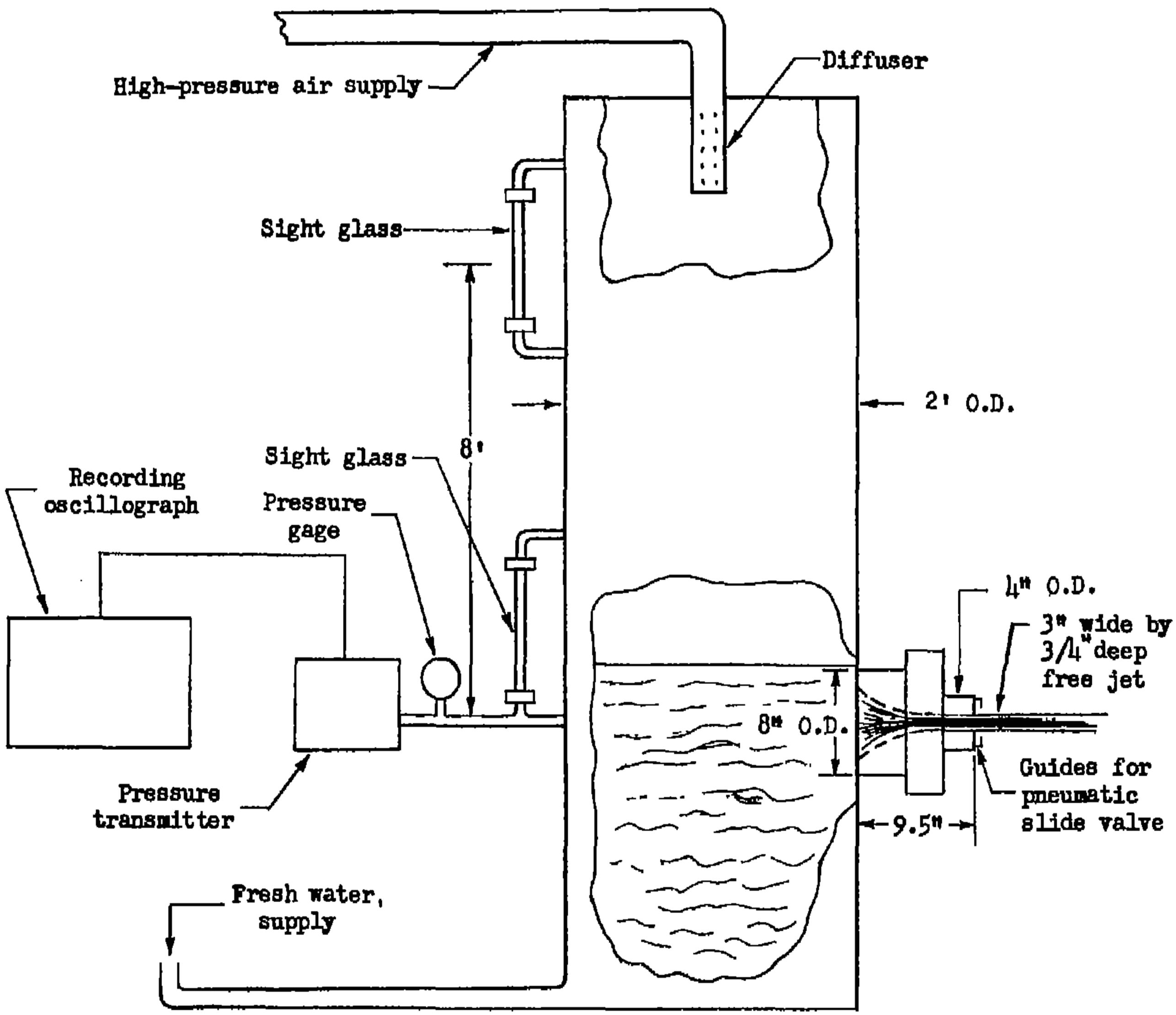
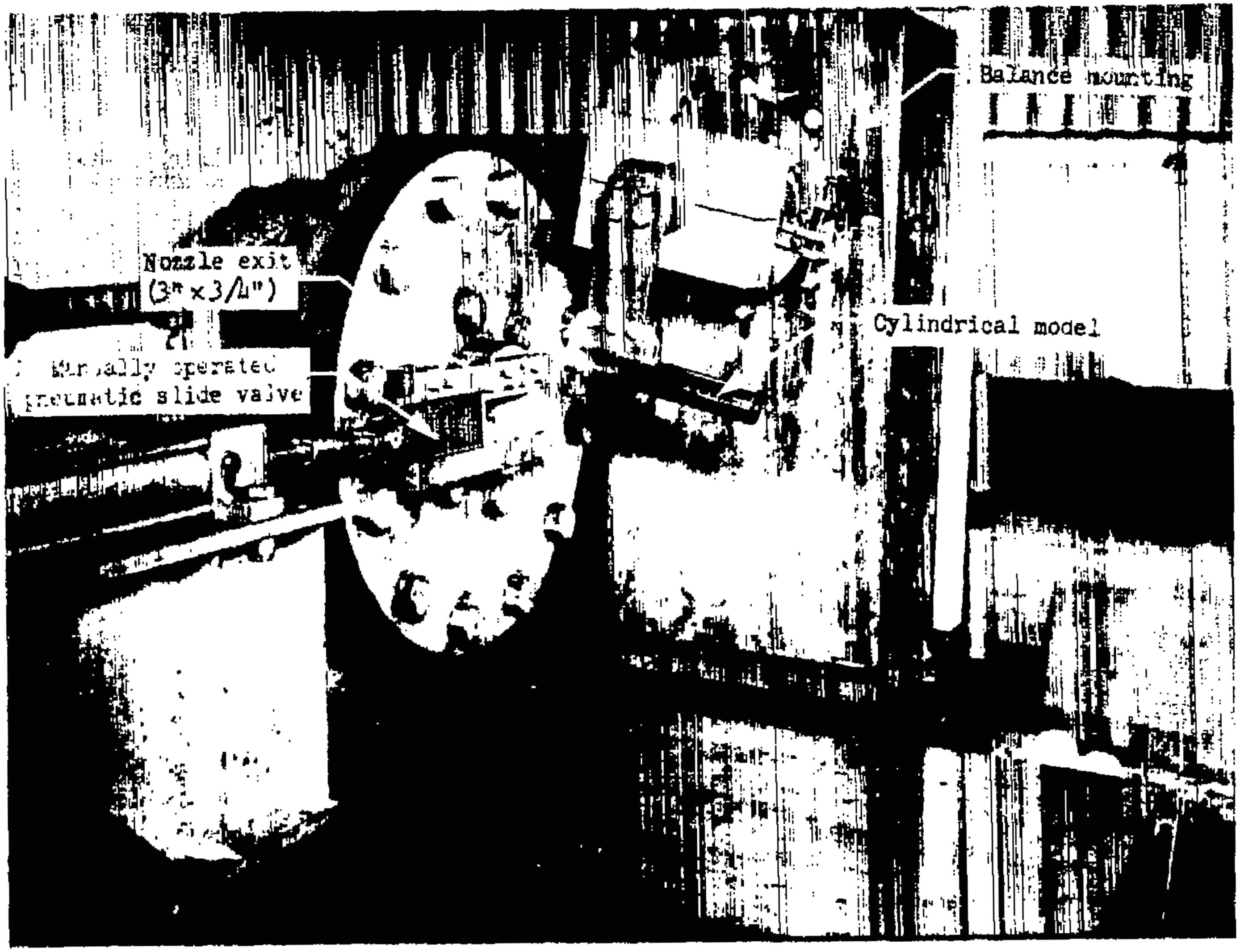


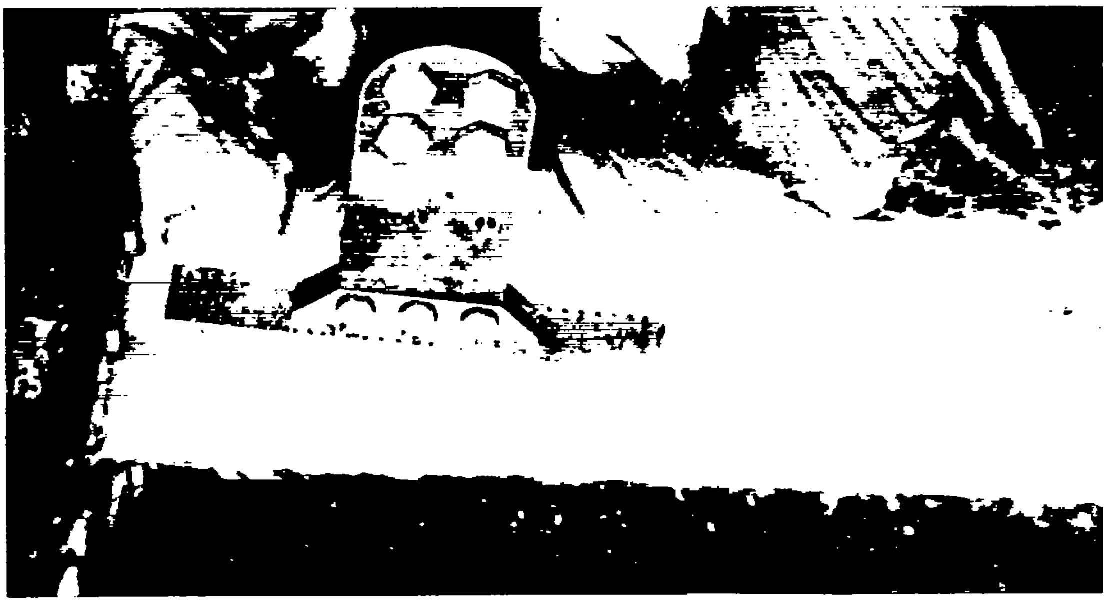
Figure 2.- Schematic drawing of equipment.



L-83685

Figure 3.- Planing surface mounted for testing.

200 fps

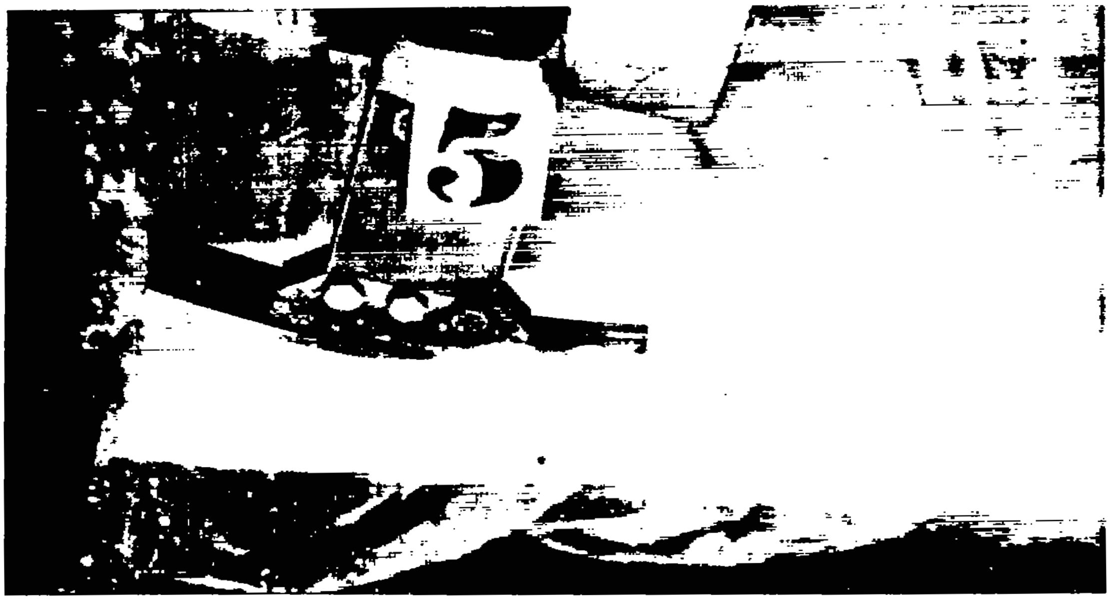


80 fps

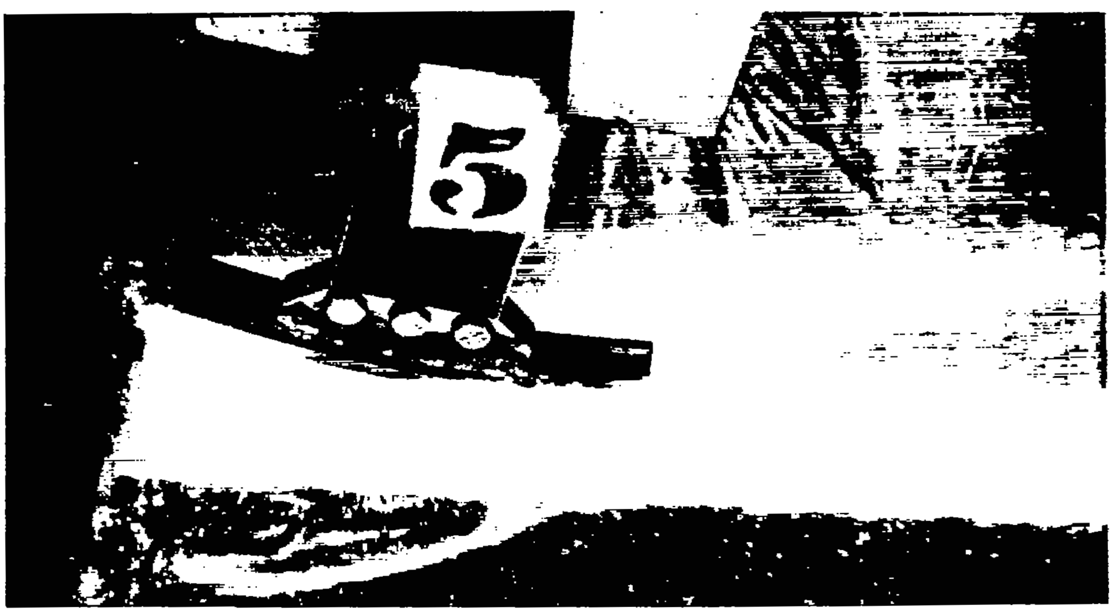
(a) Flat plate.

L-83651

Figure 4.- Photographs of models planing on jet. Trim, 8°; wetted-length-beam ratio, 2.



200 fps



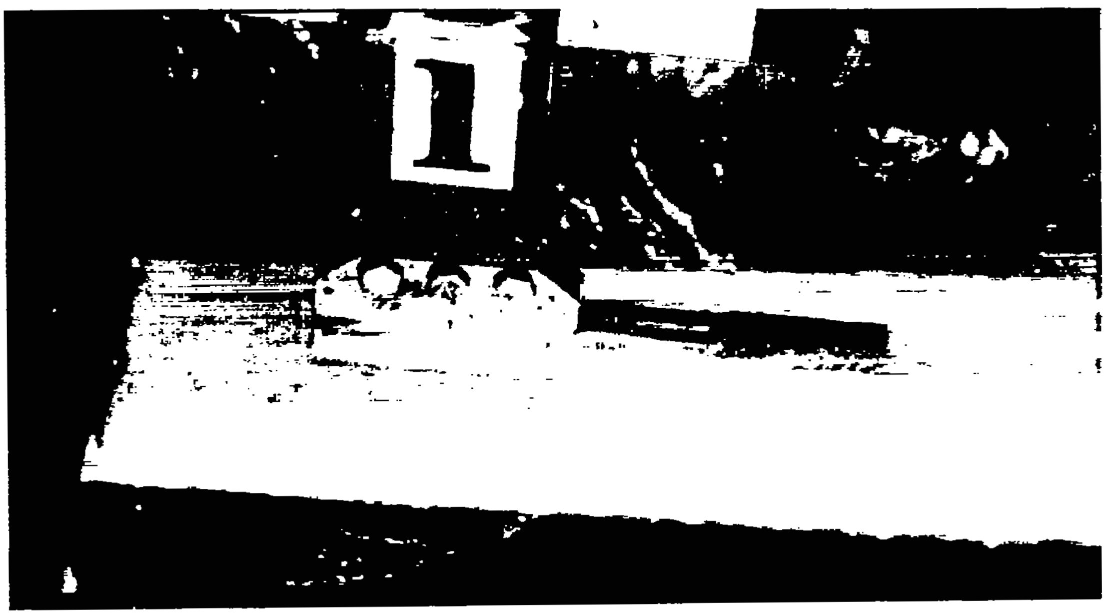
80 fps

L-83686

(b) Longitudinally curved plate.

Figure 4.- Continued.

200 fps

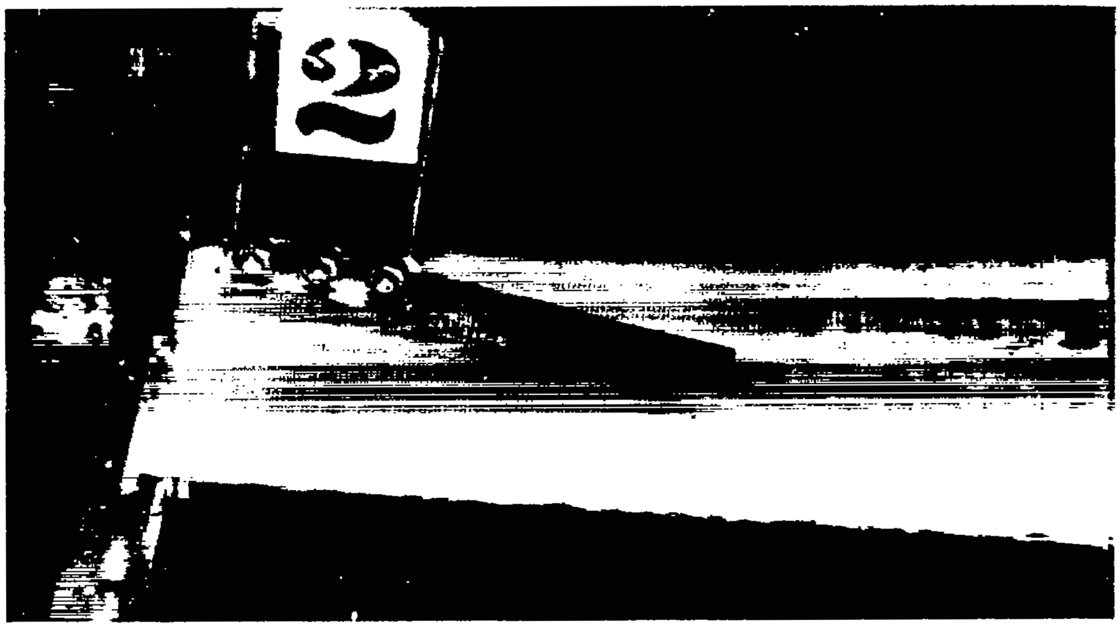


80 fps

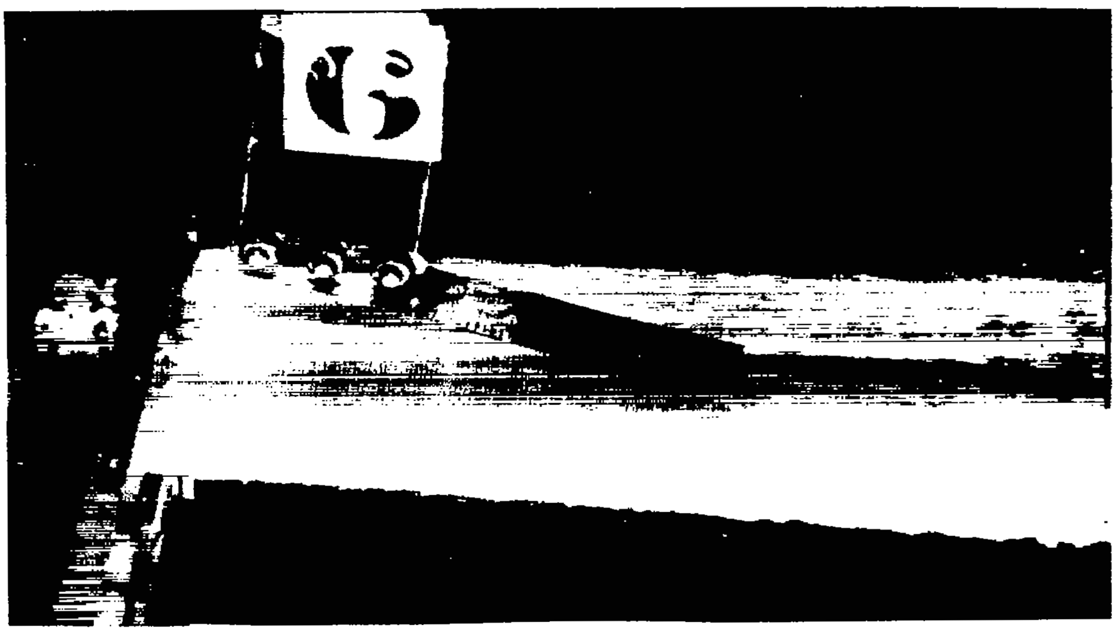
(c) Cylinder.

L-83687

Figure 4.- Continued.



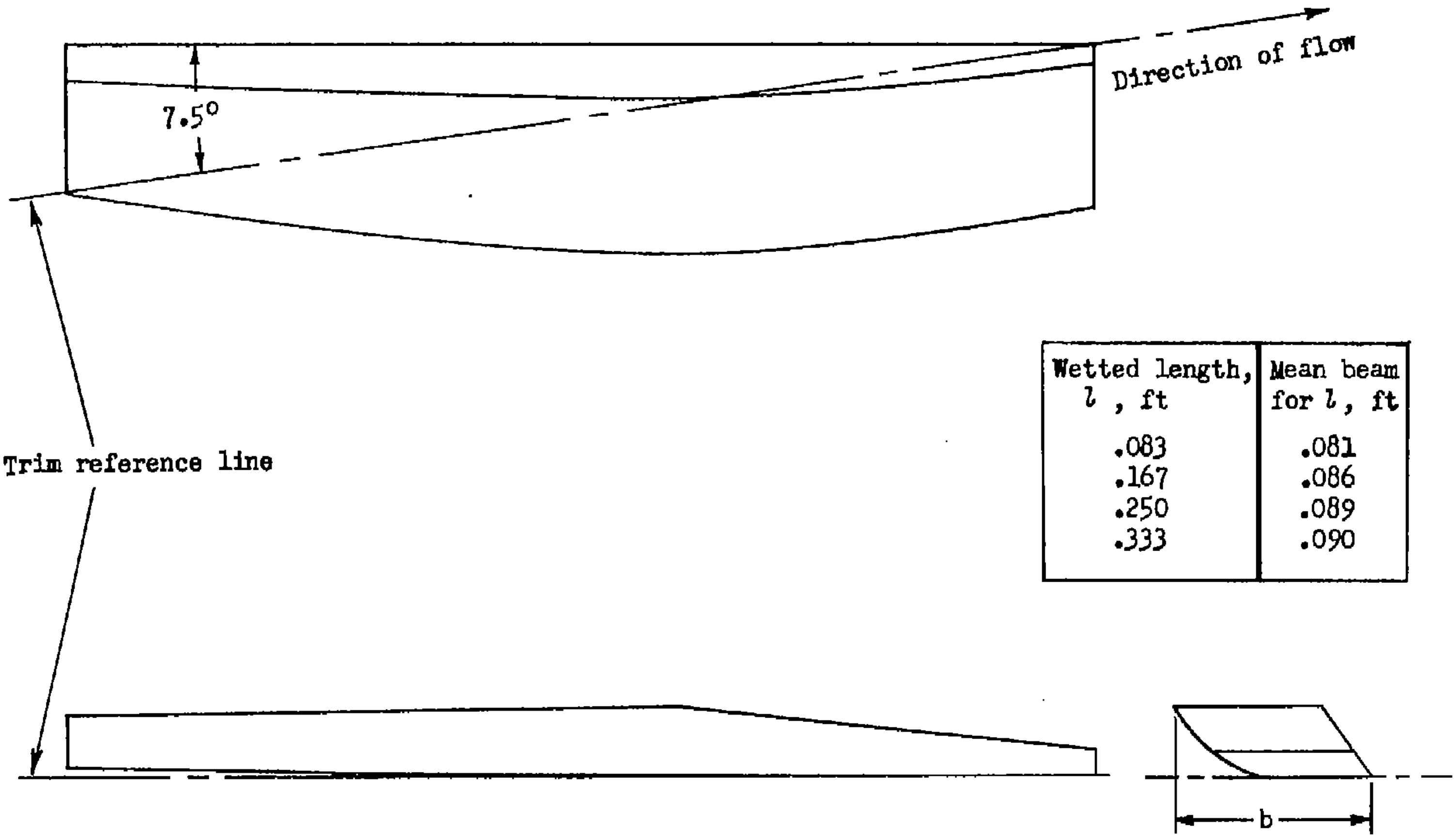
200 fps



80 fps

(d) Hydro-ski. L-83652

Figure 4.- Concluded.



Wetted length, l, ft	Mean beam for l, ft
.083	.081
.167	.086
.250	.089
.333	.090

Figure 5.- Hydro-ski configuration.

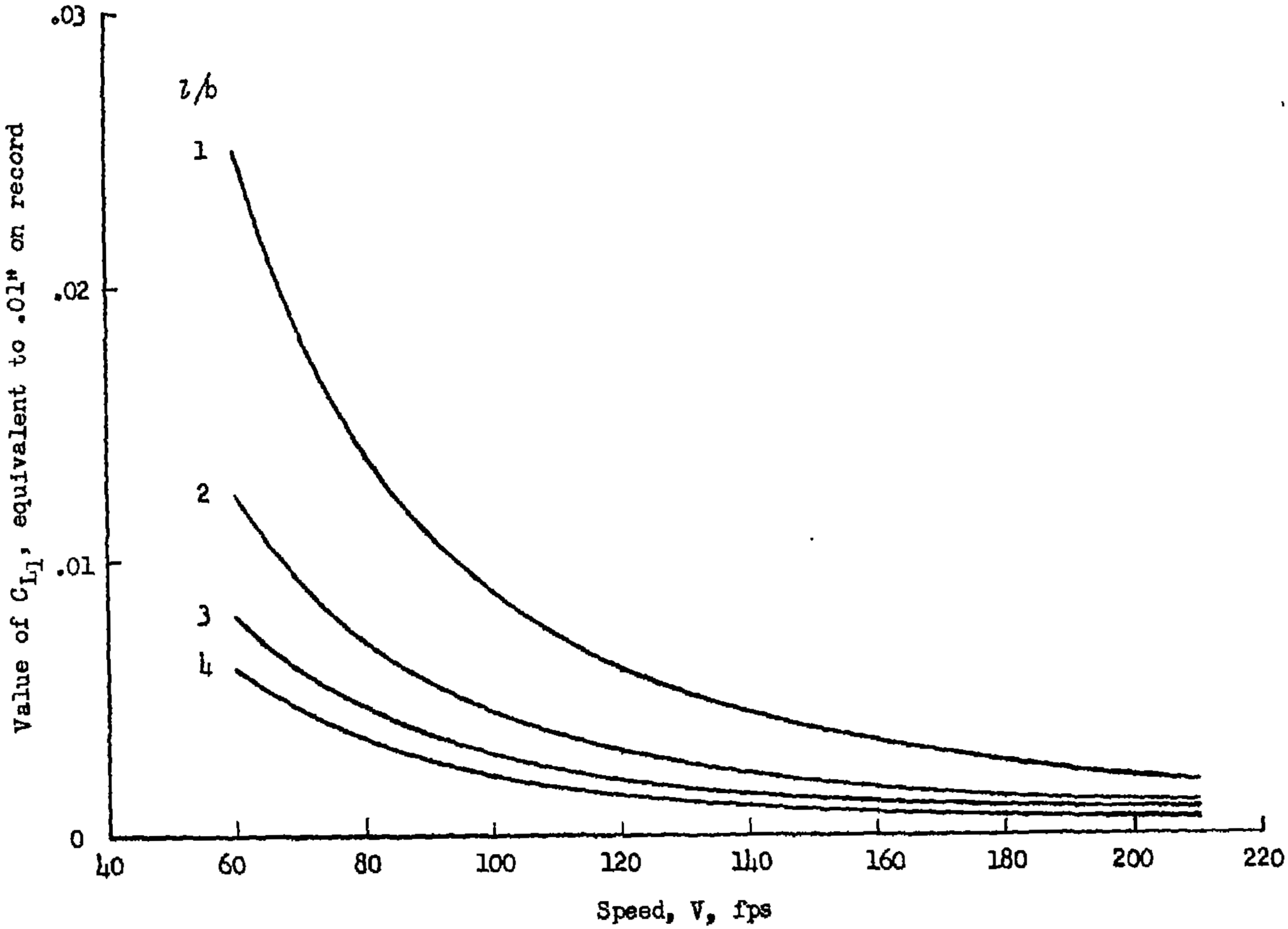
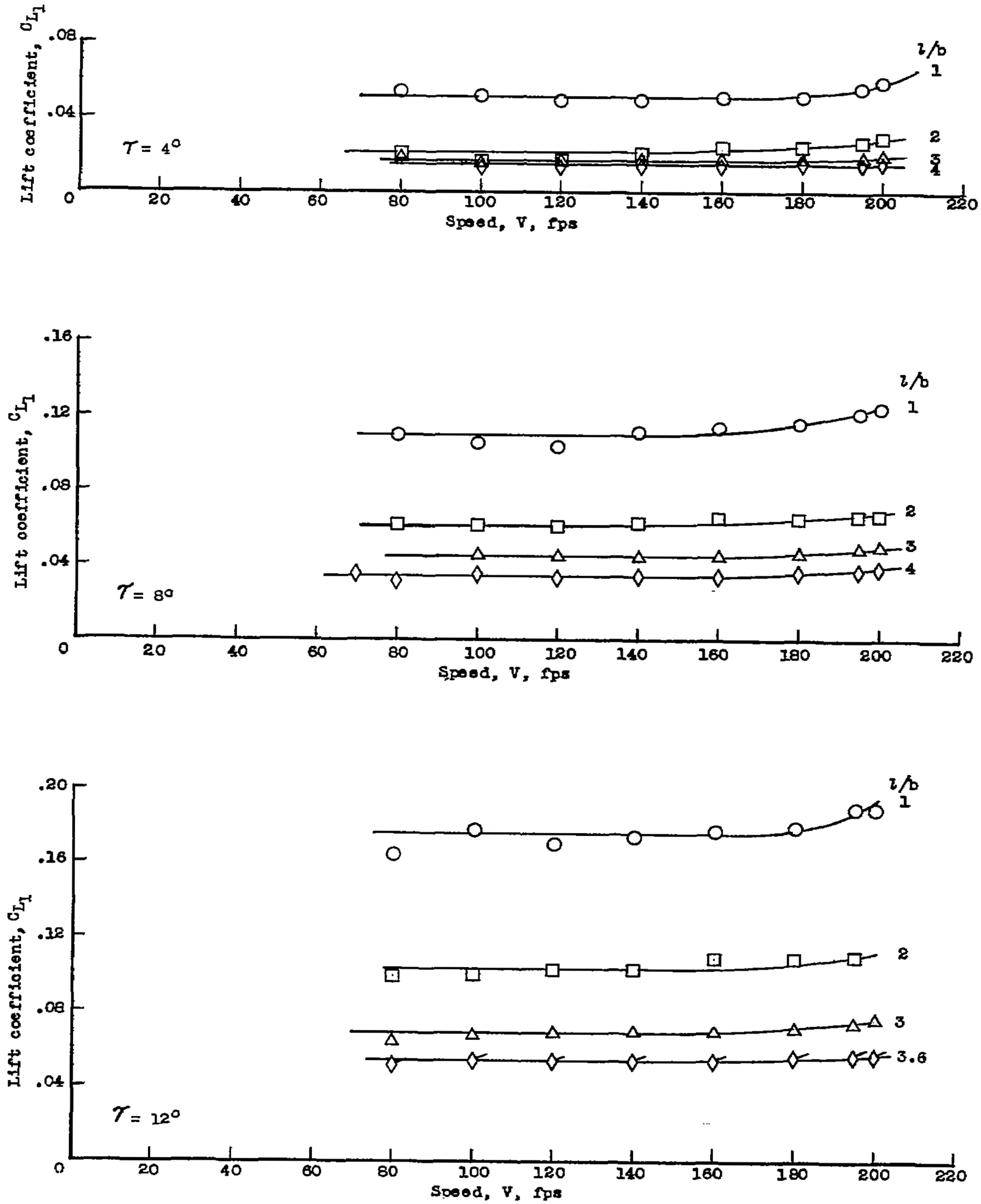
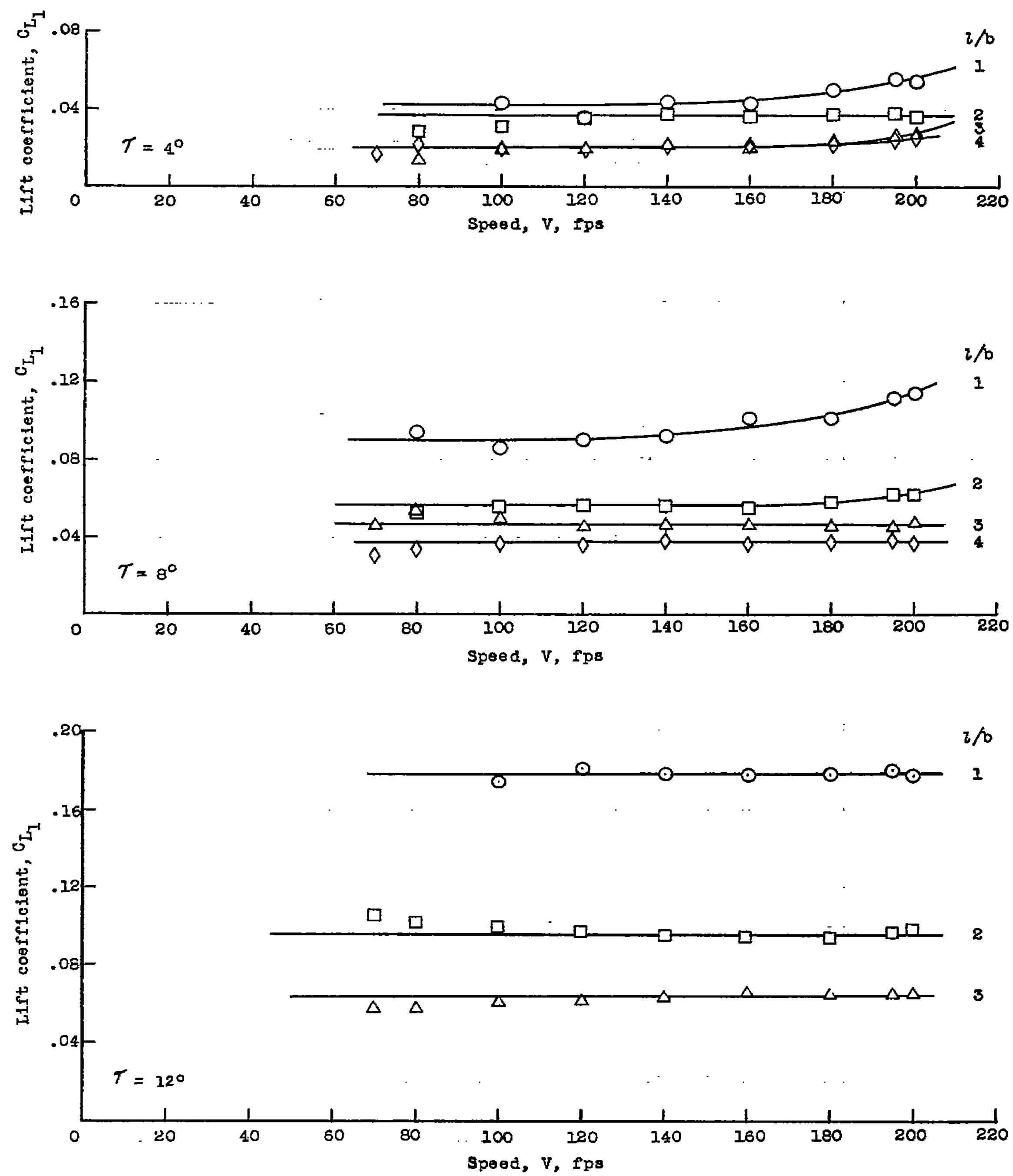


Figure 6.- Accuracy to which lift coefficient could be determined from oscillograph record.



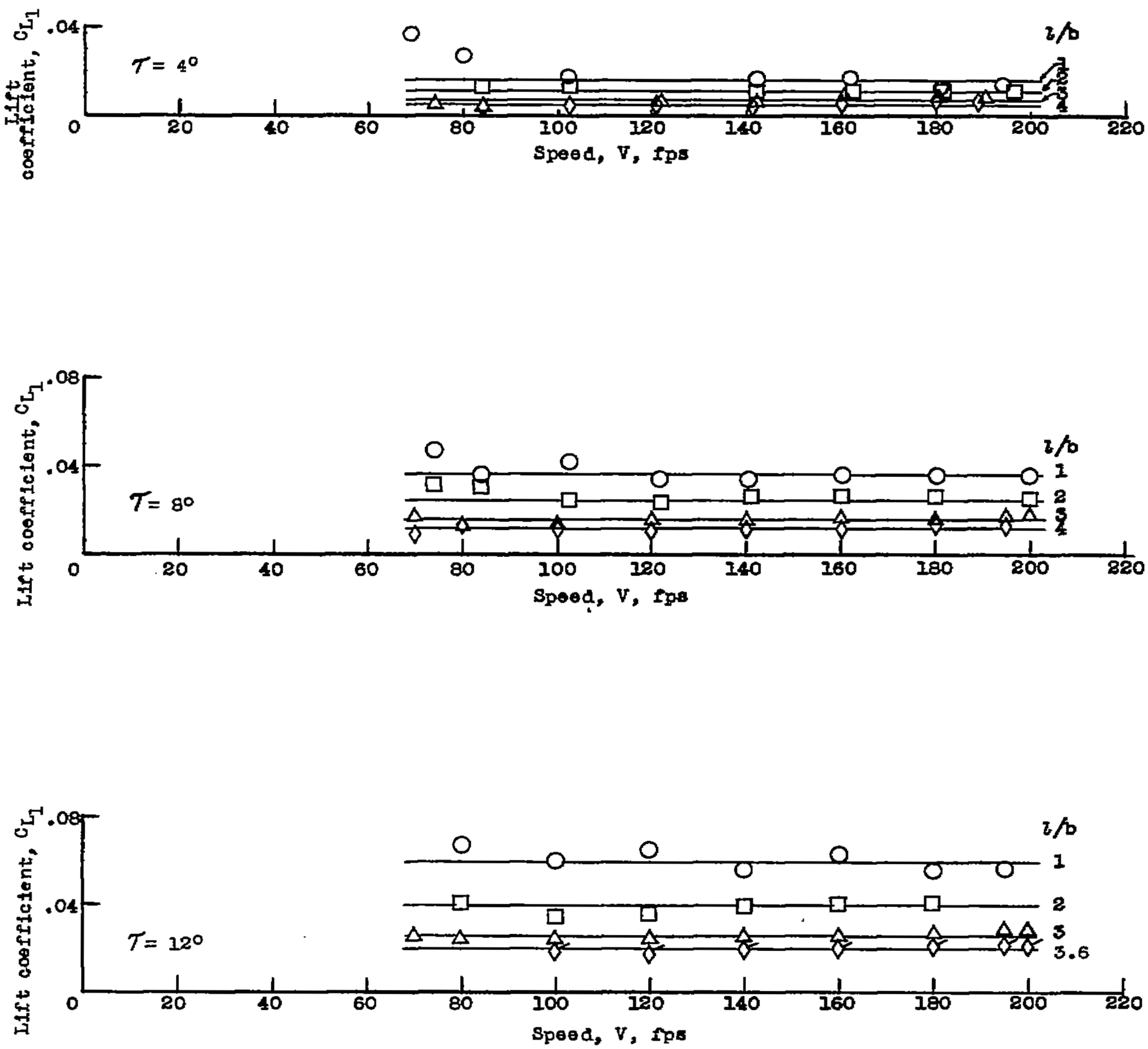
(a) Flat plate.

Figure 7.- Effect of speed on the lift characteristics.



(b) Longitudinally curved plate.

Figure 7.- Continued.



(c) Cylinder.

Figure 7.- Continued.

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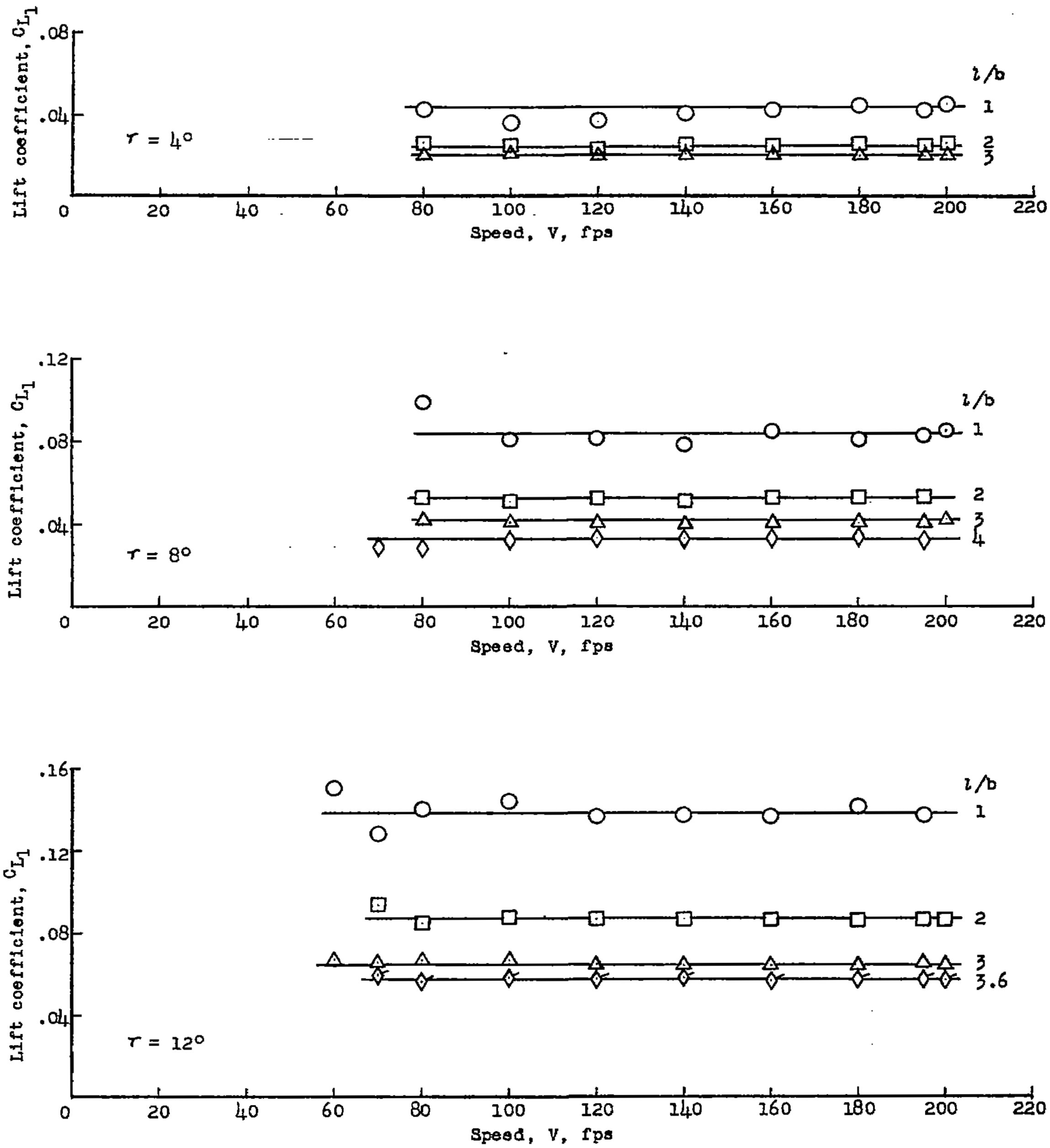
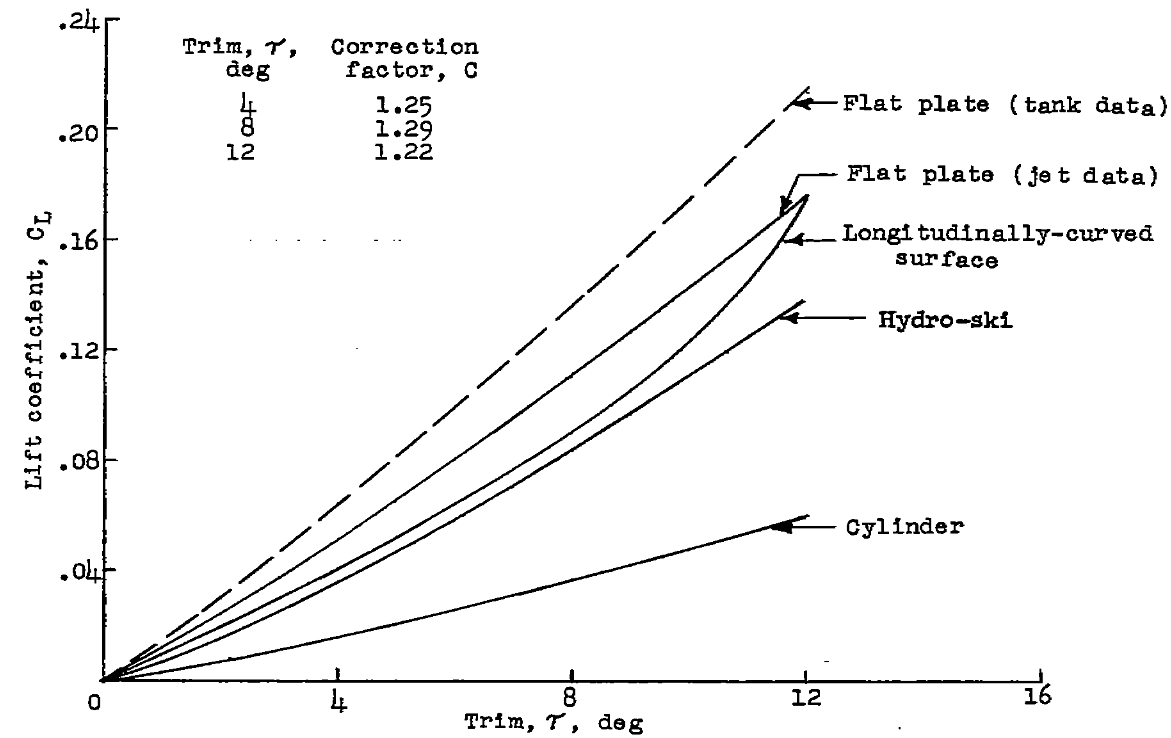


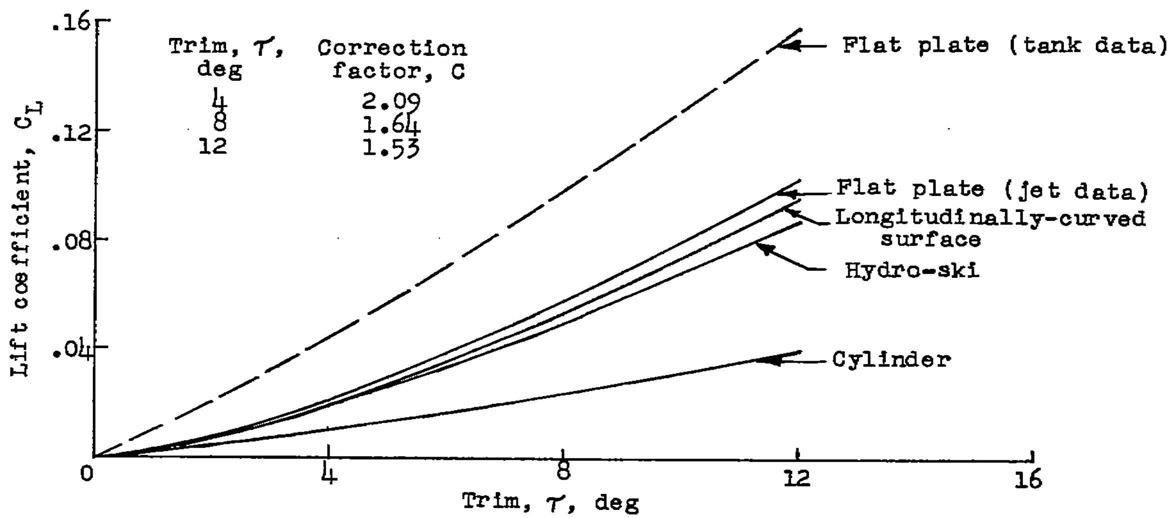
(d) Hydro-ski.

Figure 7.- Concluded.

[redacted]

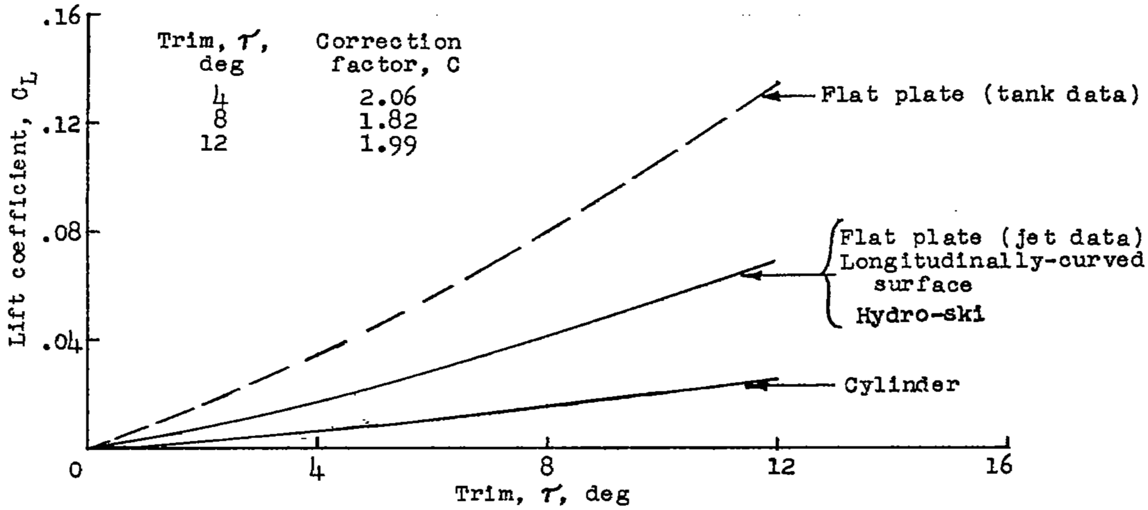


(a) Length-beam ratio, 1.

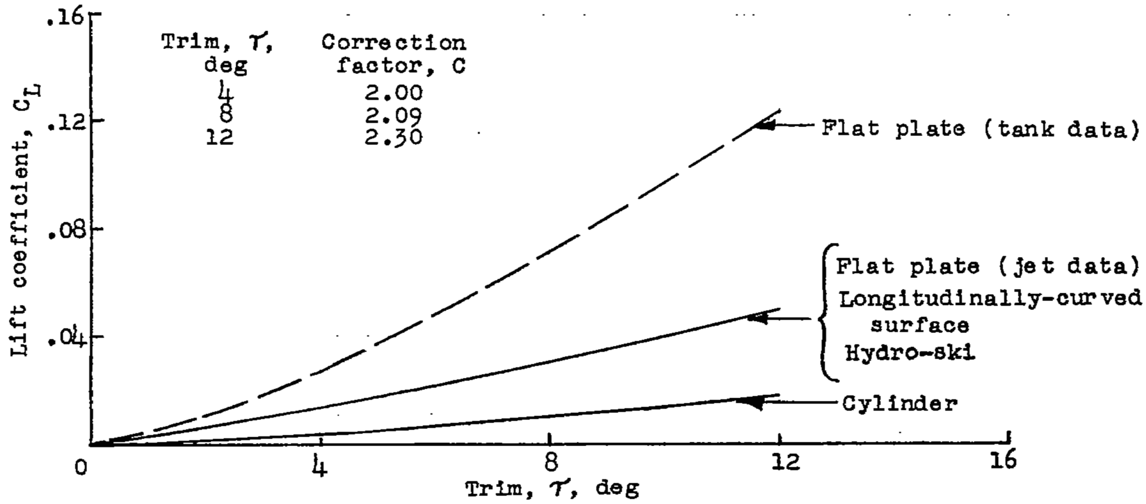


(b) Length-beam ratio, 2.

Figure 8.- Comparison of surfaces investigated. Speed, 80 fps.



(c) Length-beam ratio, 3.



(d) Length-beam ratio, 4.

Figure 8.- Concluded.

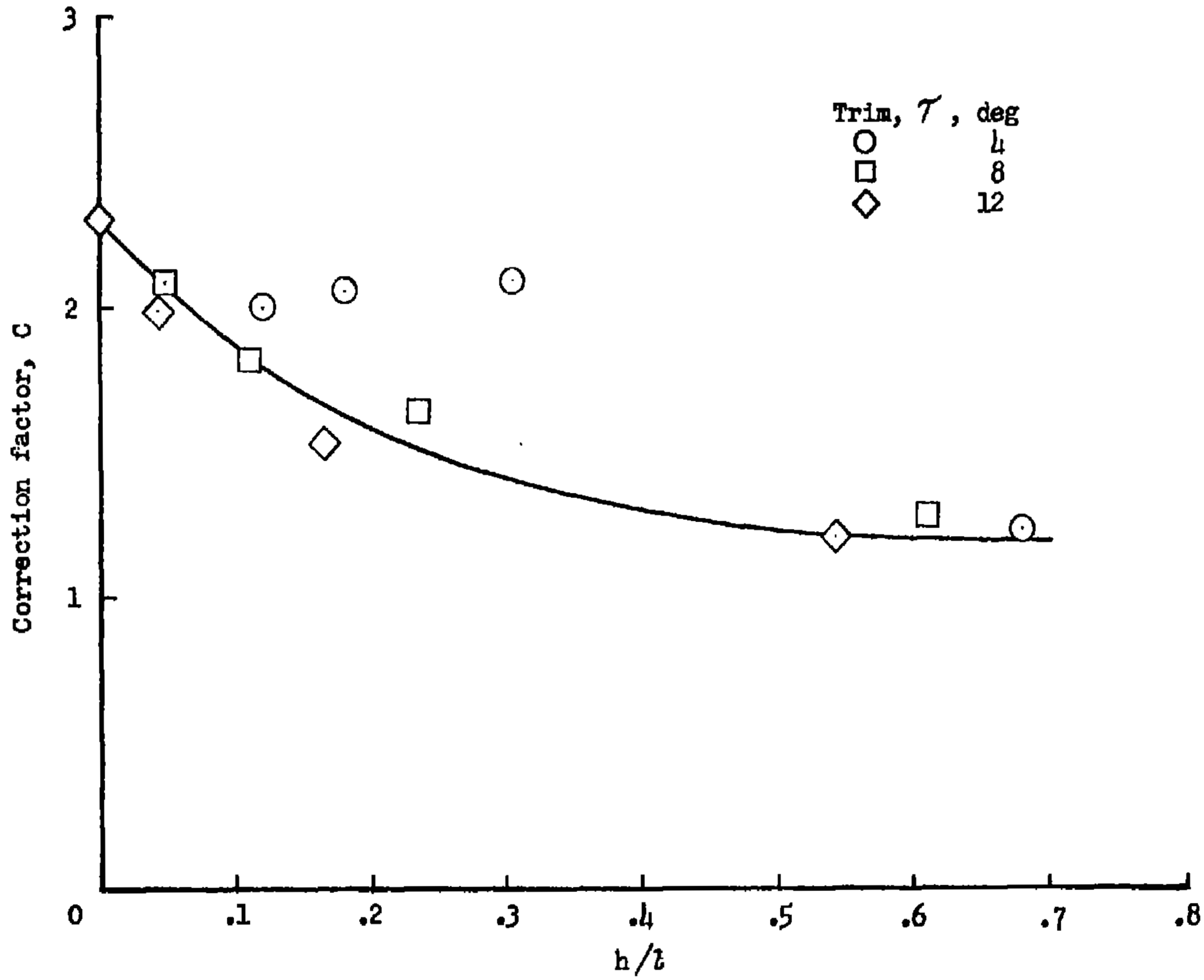
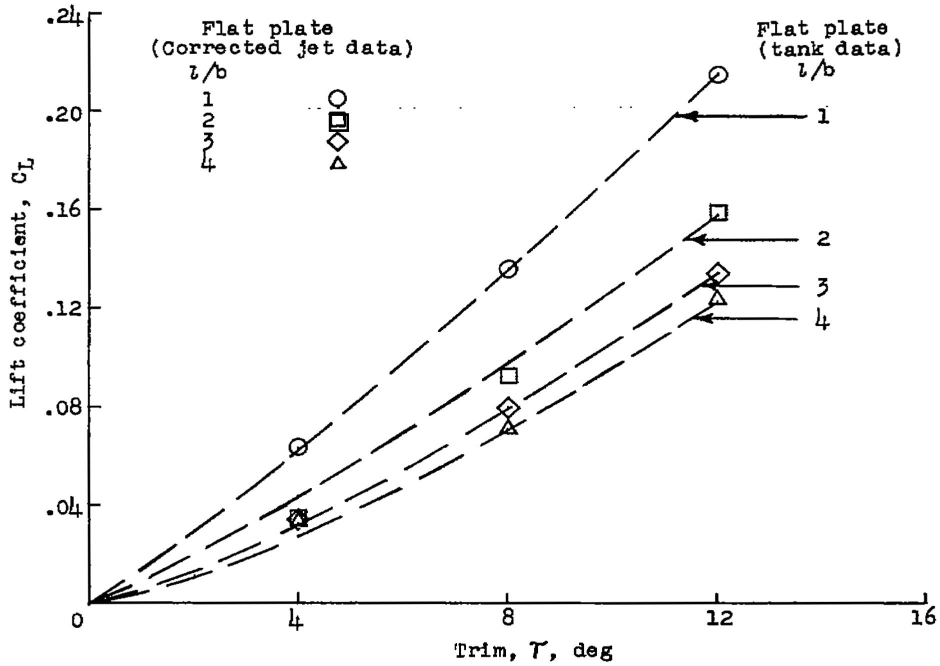
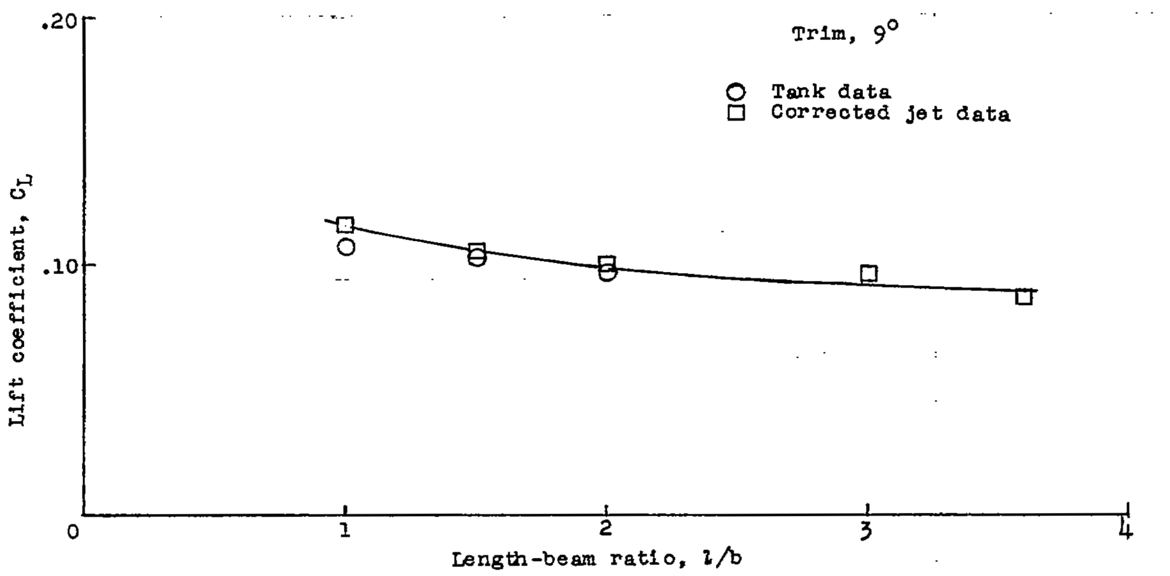


Figure 9.- Empirical correction for flat-plate lift coefficients obtained on the jet.



(a) Flat plate.



(b) Hydro-ski.

Figure 10.- Comparison of corrected jet data and towing-tank data. 80 fps.

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